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NOISE REDUCING METHODS FOR STOL AIRCRAFT APPROACH AND TAKEOFF

K. Weise and H. Anders

Translation of "Laermreduzierende An- und Abflugverfahren fuer Stol- -Flugzeuge," Messerschmitt-Boelkow-Blohm G.m.b.H., Attobrunn, (West Ger.), MBB-UH-06-73-0; DGLR-Paper 73-039; 3 May 1973. N73-31968, presented at Symposium on New Approach and Landing Techniques, 43 pages.

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16. Abstract

Noise propagation from STOL aircraft taking off and in the landing approach is investigated on 3 STOL designs. It shows that takeoff noise can be reduced by several dB by reducing the thrust (three segment takeoff) in areas near airports. Just as with CTOL aircraft, the landing paths should be as steep as possible and landing flaps and gears should only be lowered at a reduced height. The noise reduction achievable by using all possibilities in landing is considerable. Sticking to the path also diminishes noise.

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NOISE REDUCING METHODS FOR STOL AIRCRAFT APPROACH AND TAKEOFF

K. Weise and H. Anders

Summary

Noise favorable landing profiles were to be investigated for STOl aircraft. /1*
In this regard the various measures applicable to noise reduction in landing approaches were checked parametrically for their effectiveness. Three typical STOL designs were chosen as model aircraft.

In order to be able to make statements about the noise pollution of STOL transports in their entire flight near the ground the investigation was expanded to noise reduction in suitable takeoff profiles. Three segment flight profiles with thrust reduction were particularly checked in the second segment.

Particularly in steeper approach paths structural measures such as "direct lift control" systems can considerably contribute to holding the proper approach path correctly. The effects on ground noise, occasioned by this improvement in holding course, were to be ascertained.

Organization

*Numbers in the margin indicate foreign pagination.

1. Introduction /3

The sharply increasing technicalization of our environment is bringing with it a series of unpleasant and even harmful side effects. Flight noise has become environmental enemy number one for those adjacent to airports. By sharply increasing the number of landings and takeoffs per unit of time, through enormously increasing the takeoff weight of aircraft with a simultaneous transition from piston and propeller turbine engines to jet engines, flight noise has risen sharply in recent years.

For this reason the legislatures of various lands have tried by regulation, such as Part 36 of the "Federal Aviation Regulations", by post-flight prohibitions at airports, and by limiting the number of takeoffs and landings at airports per unit of time for aircraft of rather high noise emission, to restrict noise development at civil airports. Figure 1 gives a survey of the starting and landing noise of various types of aircraft in service and the noise limits stated in Part 36. It should be noted that a large proportion of aircraft no longer fulfill these requirements. On the other hand, it should be noted that the regulation of Part 36 will be made even more severe within a few years. Recommendations speak of lowering this limit to 20 EPNdB by 1980.

A reduction of noise pollution can be achieved in the following way:

a) through a choice of "milder" engines and the development of an aircraft by noise shielding at the engine inlet and at the jet or

b) by flying noise reducing flight profiles in flight near the ground (takeoff and landing).

Only the following will be stated here about point a):
Insulating the noise of engines is very expensive. Thus a sum of about one /4
million United States dollars is named as the price for reducing the noise of a four-jet aircraft full noise treatment of an existing engine in the FAR Part 36 by about 8 dB in the line of flight and about 5 dB to the side [2]. This means that a reduction in the engine noise leads to an increase in specific

engine weight and specific consumption. According to [2] to modify an engine of the 10,000 pound thrust class with a noise reduction of 7 dB it is necessary to deal with an increase in specific engine weight of 38% and an increase in specific consumption of 36%. These magnitudes also have a decisive effect upon direct operating costs.

A great deal of noise reduction, similar to that in measures concerning engines, can also be achieved by flying noise favorable starting and landing profiles, with the difference that they cost less.

In the flight manuals of a number of civil aircraft types "noise abatement procedures" are already prescribed in a very general form. However, such regulations should be more precise and, e.g., should take into consideration particularly noise sensitive zones in takeoff. Figure 2 shows a diagram for a "noise abatement takeoff flight path" for HFB 320 as it ought to be stated in the flight manual when sufficient experience has been obtained with it.

The fact that there is still not enough landing assistance available for IRF flight, such as a steeper set ILS or similar, and that increased difficulties occur in flight guidance, oppose rapid introduction of noise favorable landing profiles. Here the introduction of "automatic landing" can provide relief.

2. Definitions /5

d	Shortest distance between path segment and path observer point X_{BB} [m]
EPNL	Effective Perceived Noise Level [EPNdB]
h	Height [m]
h_o	Reference height [m]
h_1	Flight height at reduced thrust [m]
h_2	Flight height with "max. continuous" thrust [m]
OASPL	Over All Sound Pressure Level [dB]
PNL	Perceived Noise Level [PNdB]
S	Thrust [kp]

t	Time [s]
X_B	Distance of an observer point from the rising point of an aircraft [m]
X_{BA}; X_{BP}	Distance at the beginning or end of a noise sensitive area from the liftoff point of an aircraft [m]
α, β	General coefficients of damping for combined check and fan noise (see [3])
γ	Angle of ascent [degrees]
θ	Noise reflection angle [degrees] ($\theta = 0°$ in opposition to flight direction)
ψ	Angle in which max. PNL is reflected [degrees]

3. Research on Noise Reducing Flight Profiles /6

3.1 Model Aircraft and Noise Characteristics

Three different types of STOL aircraft were chosen for the model computations of noise favorable flight paths:

Type A: a conventional aircraft which achieves its full capacity with multiple slit and high lift flaps;

Type B: an aircraft which produces high lift with "externally blown flaps", and

Type C: an aircraft for which part of the lifting force is achieved by tilting the engine thrust vector.

All three types are to be equipped with General Electric TF 23 fan engines.

Table 1 shows the main data of the aircraft, Table 2 the engine data, Figures 3a-c show three side views of the aircraft, and Figures 4, 5a, 5b and 6 show the polar curves of the chosen types of aircraft.

The polar characteristic of noise for the TF 34 engine was determined with the procedure of Lee [3], Kobrinski [4], and Tyler and Sofrin [5].

The polar diagrams of noise are presented in Figures 7 and 8 for the types of aircraft with various thrust values. The noise characteristic of aircraft type C is produced from the characteristic of type A by tilting the range θ = 0°-90° by the same angle at which the thrust vector is turned to achieve lift.

In order to determine the modification of noise characteristic with flap deflection, tests were made at MBB-UH in the noise laboratory on a flap wing with a simulated fan engine. The results of these are presented in Figures 9 and 10. /7

3.2 Takeoff Profiles /8

In order to protect the zones sensitive to noise near the airport, it seems expedient to fly in noise favorable profiles rather than according to the traditional method with a takeoff configuration up to 400 feet, to draw up the flaps at that point, to accelerate and to climb higher.

Three segment profiles are to be discussed here in terms of such noise favorable takeoff profiles. When flying on such a profile, the thrust is reduced at height h_1 shortly before reaching the beginning of the noise sensitive zone, the thrust is then held constant at height h_2 until quite a distance from the zone to be protected against noise, and then again the thrust is put at the maximum permissible value.

The weakness of such a three segment takeoff profile lies in the fact that, while the noise really is sharply reduced in the regions near the airport by the thrust reduction, there is a delayed period of medium intensity distributed over a wide range beneath the flight path or in zones far from the airport after the thrust has been reduced. For this reason three segment takeoff profiles must be used intelligently under the rain "environmental conditions".

Added to this is the fact that thrust reduction at takeoff is opposed to the technical requirement of safe flight, to fly over definite points of the course at minimum flight height.

3.2.1 Procedures for Computing the Noise Favorable Three Segment Takeoff Profiles /9

The method of computation used for the model computations in the following figures was developed from a procedure of Pianko [7] with sharp modification. The computation proceeds in such a way that, e.g., in order to compute the brake point h_1, the flight noise, produced by the first segment as a function of flight height, is plotted at point X_{BA} (observation point at the beginning of the noise sensitive range) $PNdB_{X_{BA}}$ 1 segment = f(h) together with the maximum flight noise at point X_{BA} of the second segment with reduced thrust by varying the height h_1 of the first braking point of the path, $PNdB_{X_{BA}}$, maximum second segment = $f(h_1)$.

The intersection of both curves gives the height h_1 of the brake point of the course at which the smallest flight noise is produced from path segment 1 and 2 at point X_{BA}. In this same way one may proceed to determine the path brake point h_2 at which the smallest amount of flight noise from course segment 2 and 3 should be produced at point X_{BB} (observation point at end of the noise sensitive range).

Thrust reduction in the second path segment can be arbitrarily chosen before determining h_1 and h_2.

The thrust reduction will be made dependent upon the minimal permissible angle of ascent in the second segment, on the possibility of delaying noise to areas far from the airport, and on other facts. It is a fact that sharp thrust reduction produces a sharp drop in noise at point X_{BA}, because of the lesser climb of the aircraft in connection with thrust, but it produces a higher level of noise at the end of the antinoise zone.

3.2.2 Results of Three Segment Starting Profile Calculations /10

For comparison Figures 12a and 12b show the footprints (PNL and EPNL) of a three segment takeoff at heights h_1 = 404 m and h_2 = 520 m, respectively, a straight-line path for aircraft type A. During the flight along the path the speed and flap position were held constant ($V = 1.3\ Vs$; $\eta_k = 20°$).

A comparison of the two diagrams shows a tangible reduction in noise in the area near the airport for the three segment takeoff. Actually the noise is strictly delayed until areas far from the airport are reached.

The extent to which the noise is postponed from the zones near the airport also depends on the thrust-weight ratio of the type of aircraft. Figures 13a and 13b show the footprints plotted for aircraft type C (same speed and flap position as type A).

While it is true that this aircraft type generally produces a higher noise level in the area near the airport, the noise level drops essentially faster with distance from the lift point as in the weaker thrust type A (see aircraft data Table 1).

The noise levels PNL and EPNL for several observation points and varying h_1 and h_2 are plotted for type A in Figures 14a and 14b. The diagrams clearly show that there are different profiles for the least noisy flight profiles at different observation distances from the liftoff point. The position of h_1 is primarily decisive for zones near the airport, while for observation points distant from the airport the most noise favorable proves to be a straight course, i.e., h_2 coincides with h_1.

This three segment flight profile is especially suitable for STOL systems /11 which are supposed to operate from special "STOL-Ports". But it is to be assumed that because of their special task the latter will have a smaller area of structures to protect than conventional airports have. Here it is primarily the areas near the airport which require protection against noise. But the very general rule that the straight-line courses as steep as possible are the most noise favorable (which is really valid only for areas far from airports), does not apply to the former.

3.3 Landing Approach Profiles /12

Determination of noise favorable landing approach profiles is not an optimization task, since it is clear that minimum flight noise is achieved when the lowest engine thrust is used and the distance between all observers as far as possible in the approach sector and the aircraft is very great. Very low thrust produces lower noise emission from the engine. Large cruising flight heights in the approach sector make steeper approach paths necessary.

Because of the very simple relationship between angle of glide, resistance and thrust

$$\gamma = \arcsin\left(\frac{S - W}{G}\right)$$

a lower thrust is produced for the desired steep approach, i.e., very great. If the approach angle is limited, the thrust can be further diminished by reducing resistance. This means that the modifications in configuration sharply increasing resistance on landing, such as lowering landing gears and fully extending flaps, should be made very late at the end of the approach.

3.3.1 Noise Propagation with Various Flight Profiles /13

In the following only the noise propagation of various approach profiles for STOL aircraft will be investigated parametrically. The calculation is based on the data provides in Chapter 3.1.

Low Drag Flight:

Because of the sharp rise in drag and the concomitant increase in thrust when lowering the landing flaps and gears, the possibility of producing the landing configuration very late in the approach makes possible a greater reduction in the noise threshold for mean noise levels. This is particularly true for aircraft types which increase their noise emission greatly when using flaps (here types B and C). Figures 15a and b show the footprints for these types with different flap heights ($\gamma = -3°$).

Landing on a Straight Course at an Approach Angle of Varying Steepness:

As to be expected, steeper flight paths produce a sharp reduction in flight noise in the approach sector, especially in the areas far from the airport. Figure 16 shows the noise level for type A at various observation points and approaches of differing steepness.

Landing in a Simply Broken Path with the Brake Point at Differing Heights:

Since steep approach paths cannot be flown up to the landing point by rapidly approaching types of aircraft, it is at least possible for a sharp reduction in noise to be achieved for the area distant from the airport by beginning the approach path with a steep segment and shifting to a flat segment near the airport. Figure 17 presents the footprints for type A in a number of such paths.

Approach on Approach Paths Broken Several Times: /14

If the transition from a simply broken approach path from one very steep first segment to a flat second segment is too difficult from the technical point of view of guiding the aircraft, this transition can be subdivided so that more path segments occur. Just as the simply broken paths, these multi-broken approach paths have the considerable advantage of noise reduction from the steep paths combined with a final flat portion before setting down. Figure 18 represents the footprints of aircraft type A at landing from doubly broken paths. Let us call attention to the fact that paths with a constant modification in glide angle (e.g., parabolic baths) are approached by way of multiple broken paths. However, these cannot be flown manually. But they are seen as approach paths in future automatic landings.

Approach Paths with Horizontal Approach at Various Heights:

The footprints for approaches of aircraft type A are presented in Figure 19, where the glide path ($\gamma = -3°$) is followed horizontally at various heights. The transmission from the cruising flight configuration into the landing configuration occurs on the glide path at 12,000 feet. In areas far from an airport the noise level can be moderately improved by equator heights of overflight.

The results show that greater noise reduction is to be reached for STOL aircraft in the approach sector by the use of suitable approach profiles.

3.3.2 Reduction of Noise Propagation by Exact Course Holding /15

Another interesting question is the accuracy of staying on path on the approach profiles. Uneven course flying adds to noise pollution from three points of view.

a) Height deviation below the proper path lessens the distance to the noise sensitive zones (overflight height), and this acts as a higher noise level on the ground.

b) A height deviation below the proper path must be corrected by reducing the angle of glide, i.e., by increasing thrust. This means additional increase in noise.

c) Frequent modification of the noise intensity of the engines is perceived as an additional increment to the noise level. Therefore an effort must be made to achieve a steeper approach path through better course holding. As a number of investigations have shown (e.g., [9, 10]), "Direct Lift Control" systems can help considerably in holding course better, moreso than by conventional height guidance. Figure 20 shows the noise propagation on landing of aircraft type A, $\gamma = -6°$, once on a straight path and once with a deviation of $\pm 0.75°$ from the proper course. Course correction is made with conventional height control and by thrust modification. The form and magnitude of the footprints show that noise is increased because of thrust increase and shorter distance to the ground because of inaccurate course at places where a deviation of the aircraft below the proper flight course is corrected, and on the other hand for that noise is reduced at places where a deviation above the proper path is corrected.

If success is found with a suitable guidance system in achieving as little deviation from the proper course as possible, the footprint for maximum deviation will approach a straight-line approach path.

4. Summary /16

Takeoff and landing approach profiles were investigated for various STOL designs with reference to noise propagation.

Three segment takeoff profiles, in which thrust is throttled after takeoff at definite heights, proved to be favorable takeoff procedures for reducing noise. This led to noise reduction in areas near the airport, but to slight increases in noise level far from the airport.

What is true for CTOL systems is also true of landing approaches for STOL aircraft. The approach paths should be as steep as possible and should be flown as far as possible with low resistance, i.e., landing flaps and gears should be lowered as late as possible. When all possibilities are used noise reduction during the landing approach of STOL aircraft is considerable.

Holding precisely to the flight path also has a noise diminishing effect. This is achieved by avoiding underflying the flight path with its concomitant shorter distance between the aircraft and observer, and by avoiding thrust

shorter distance between the aircraft and observer, and by avoiding thrust increase for course correction.

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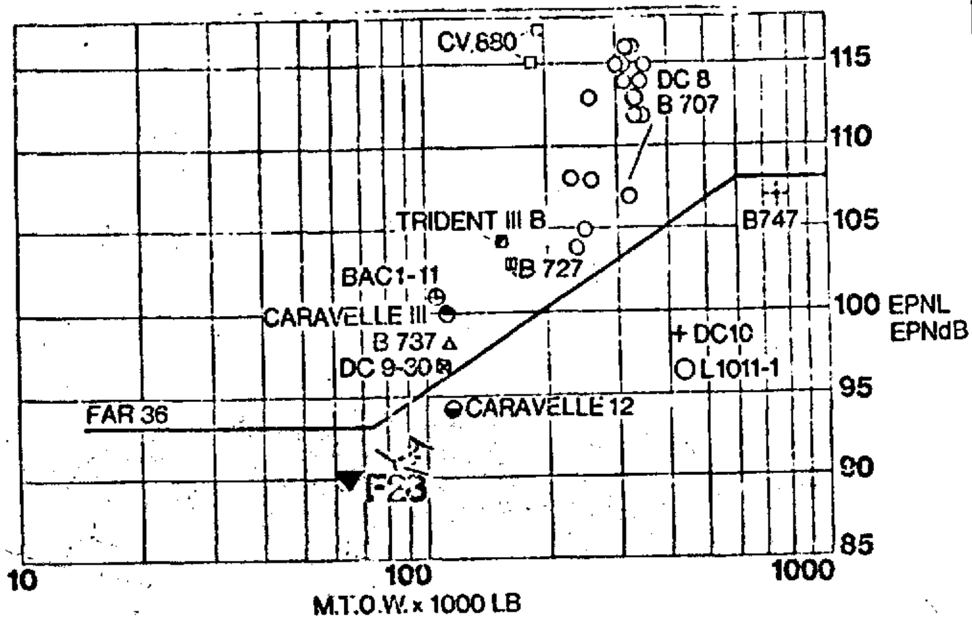
Table 1: Main Aircraft Data /19

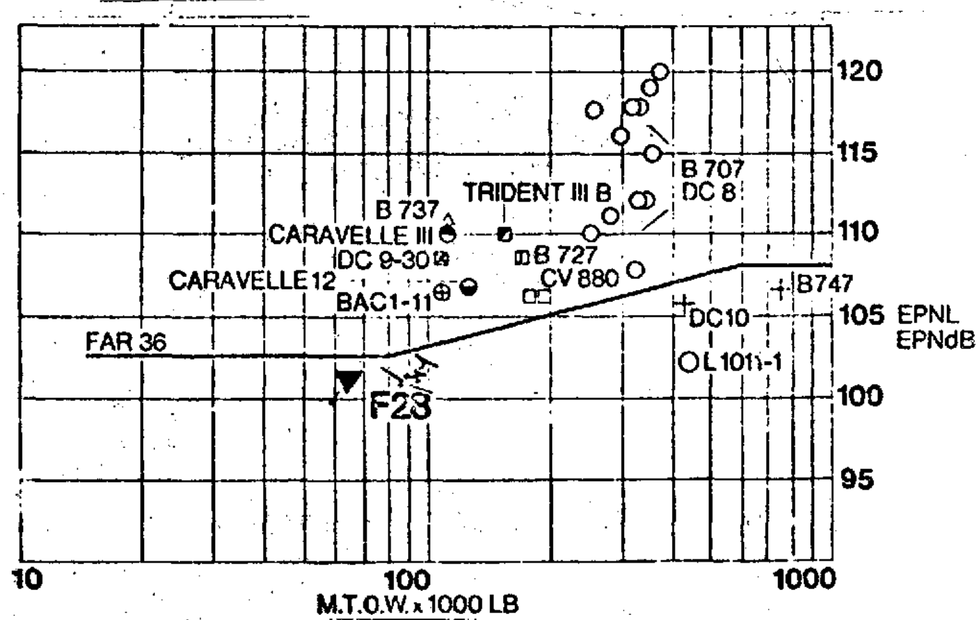
	Type A	Type B	Type C
Max. Takeoff Weight [kp]	31500	29000	33750
Max. Landing Weight [kp]	31500	29000	33750
Lifting Surface [m^2]	143	100	91
Number of TF 34 Engines	3	4	4

Table 2: Main Data of TF 34 Engine

Max. Takeoff Thrust, ISA, SL	4220	[kp]
Bypass Ratio	6.23	
Primary Jet:		
Blow Down Velocity (Ma = 0.2)	442.3	[m/s]
Density	0.359	[kg/m3]
Jet Surface	0.1362	[m^2]
Secondary Jet:		
Blow Down Velocity (Ma = 0.2)	269.5	[m/s]
Density	1.125	[kg/m3]
Jet Surface	0.4512	[m^2]
Mass Throughput	157.67	[kg/s]
Fan:		
Diameter	50	[inch]
Number of Blades	28	
Max. Continuous Revolution	7455	[rpm]
Number of Stator Blades	44	



Takeoff Noise (Overflight Noise)



Landing Noise

Figure 1. Takeoff and Landing Noise of Various Aircraft Types According to FAR Part 36.

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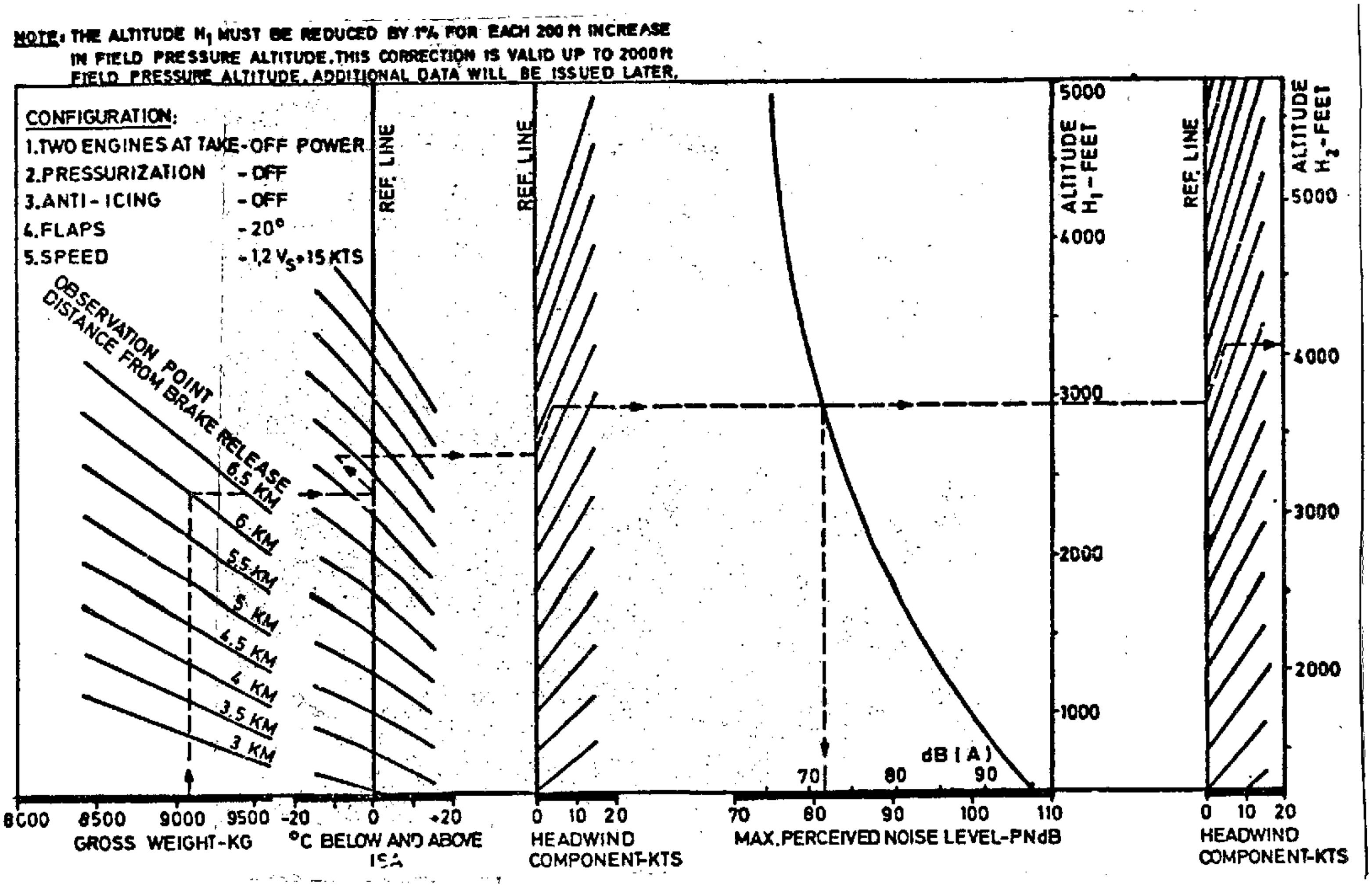
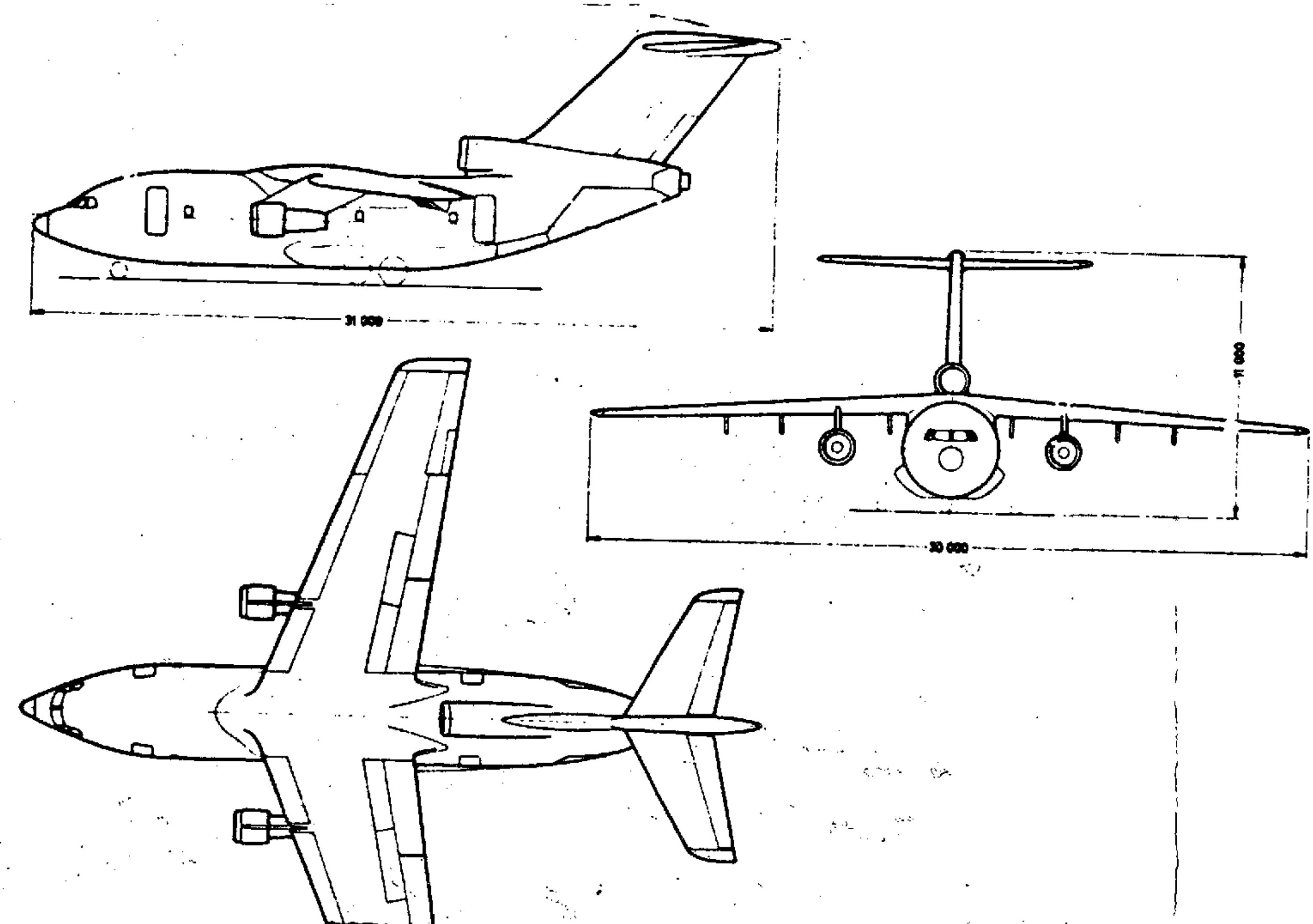


Figure 2. Noise Abatement Takeoff Flight Path Altitudes. Field pressure altitude: Sea Level.



Measurements in mm.

Figure 3a. General Sketch - Type A.

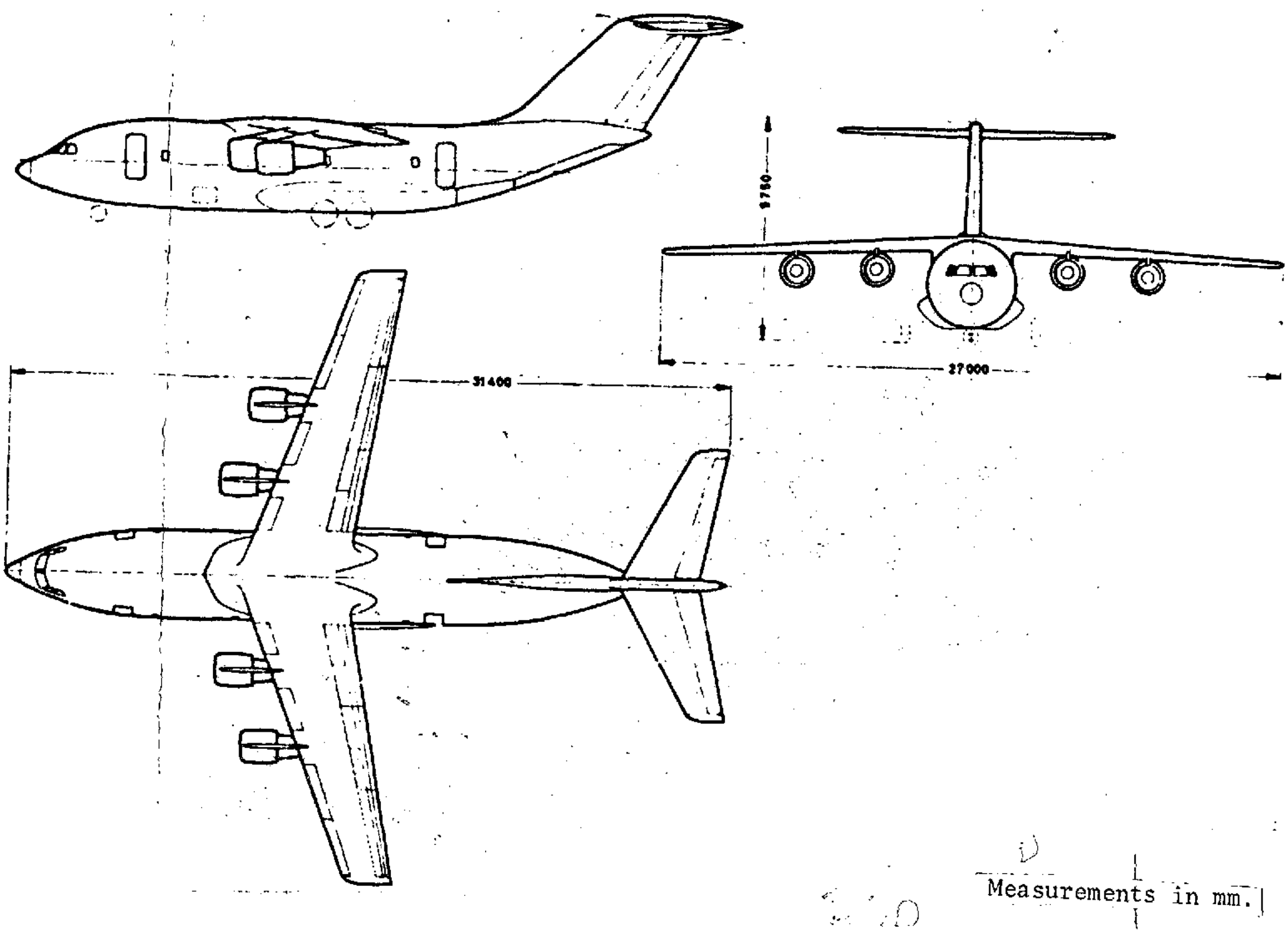


Figure 3b. General Sketch - Type B.

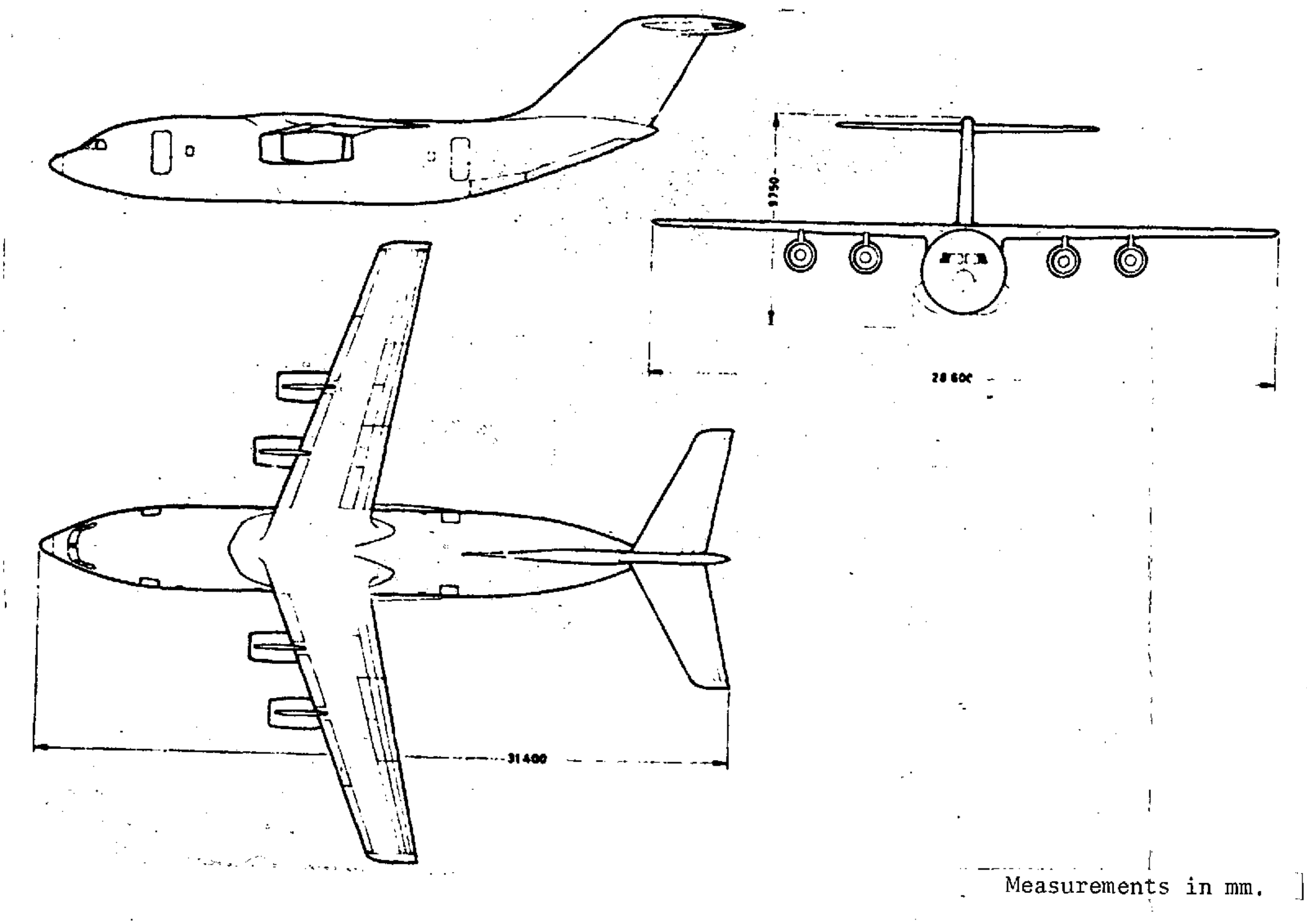


Figure 3c. General Sketch - Type C.

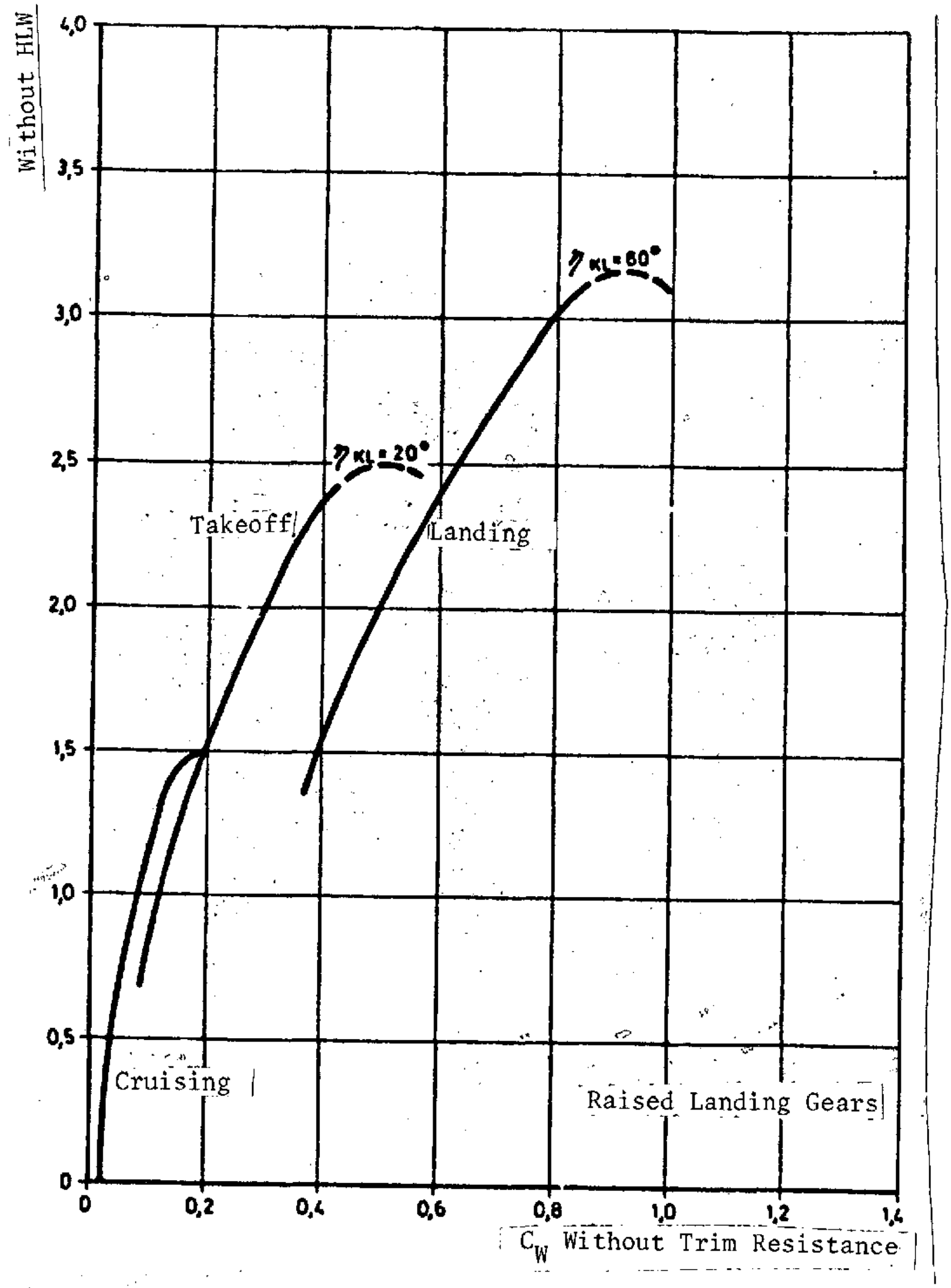


Figure 4. Polar Curves for Type A.

*Note: Commas indicate decimal points.

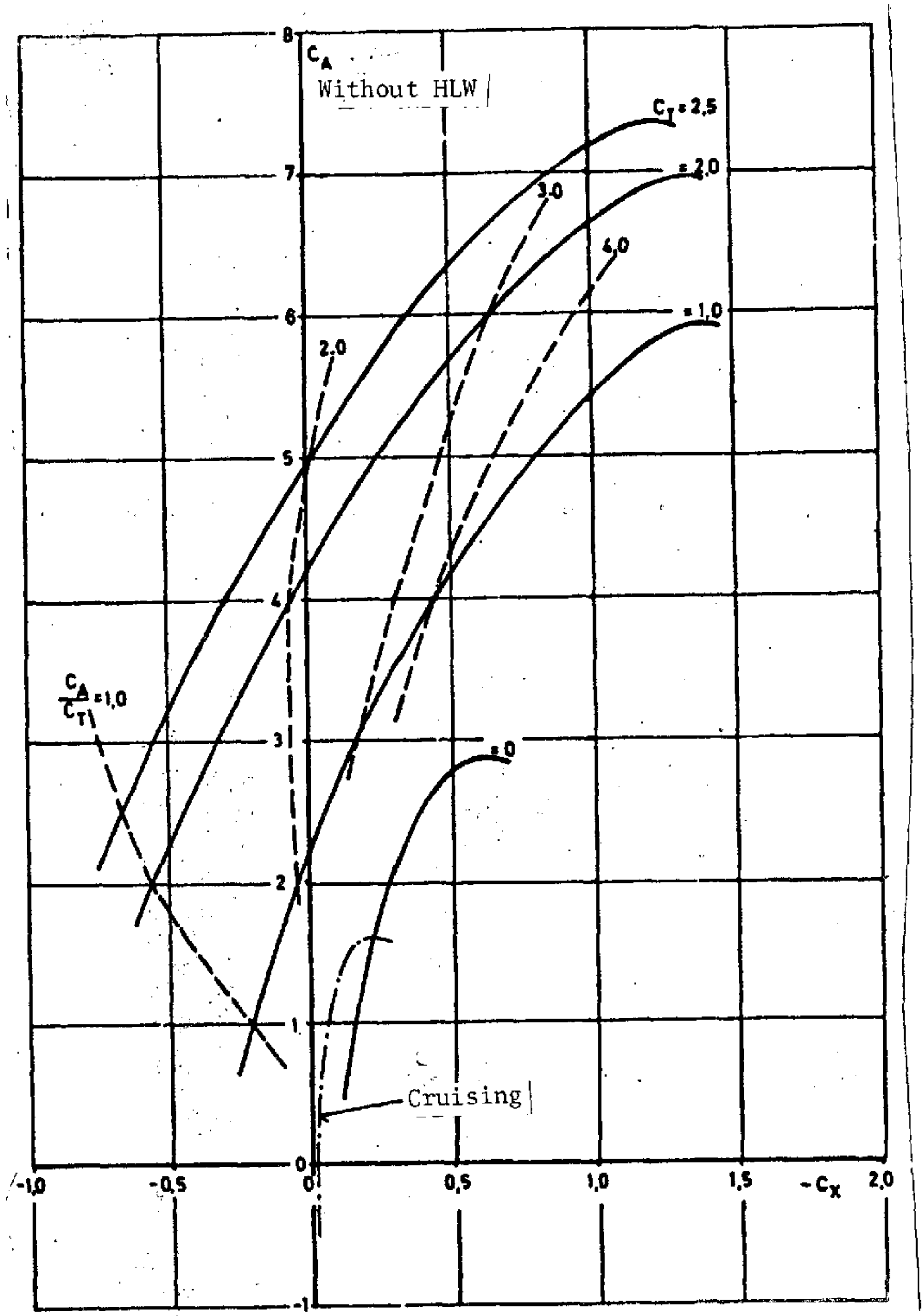


Figure 5a. Polar Curves for Type B, $\eta_{KL} = 45°$.

*Note: Commas indicate decimal points.

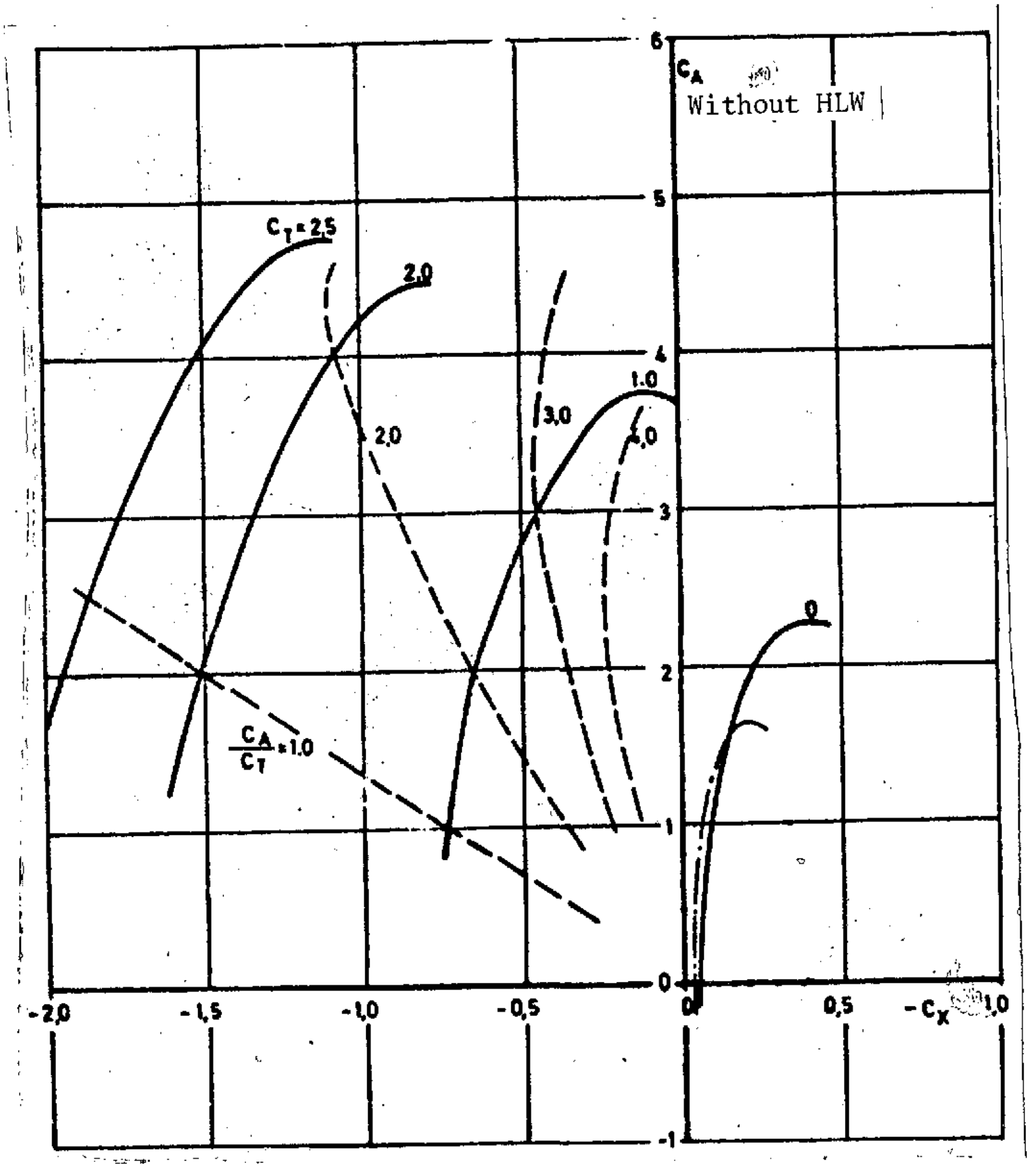


Figure 5b. Polar Curves for Type B, η_{KL} = 15°.

*Note: Commas indicate decimal points.

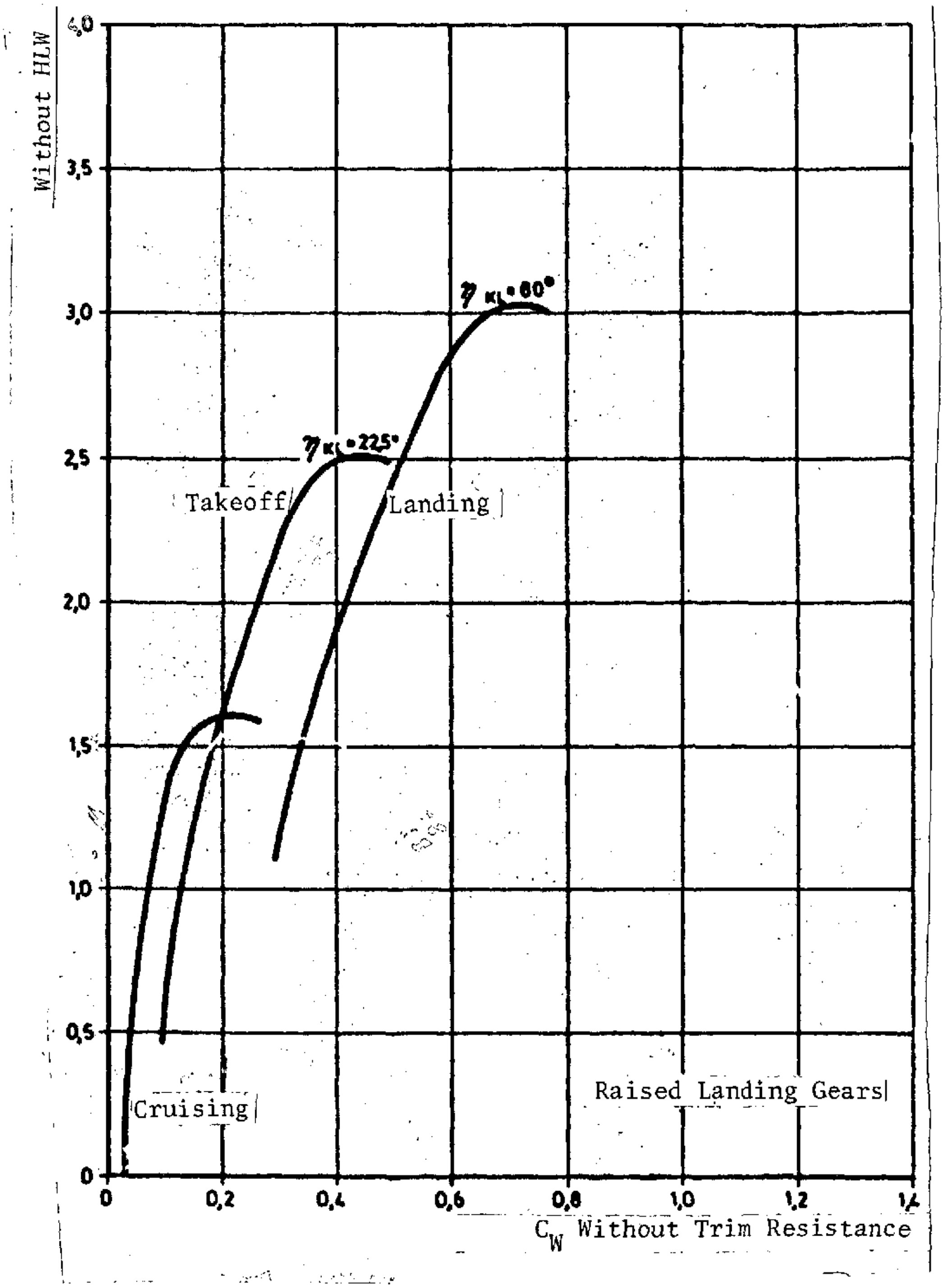
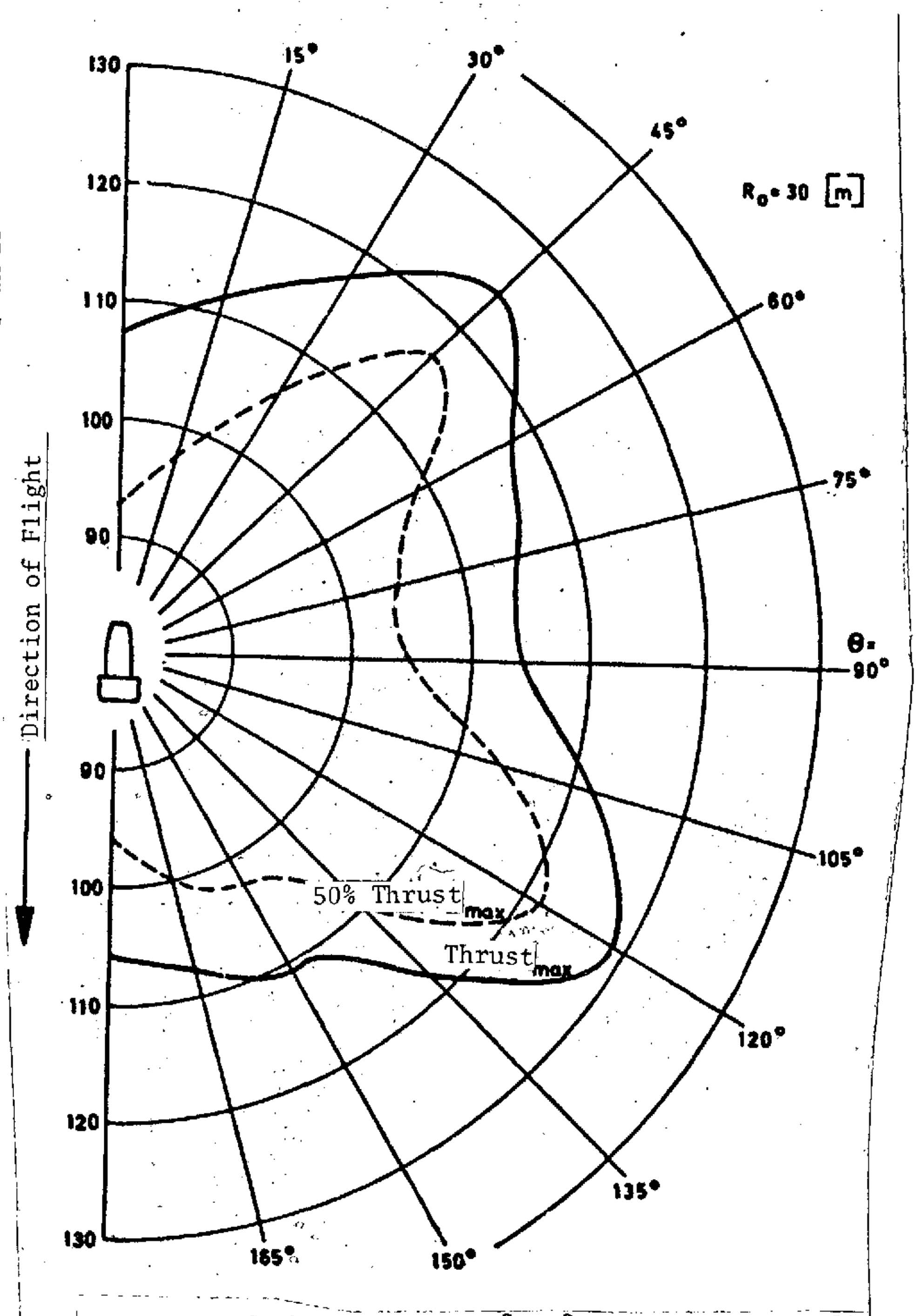


Figure 6. Polar Curves Type C.

*Note: Commas indicate decimal points.



For Type C the range θ = 0°-90° is rotated by 30° at takeoff and by 65° at landing.

Figure 7. Noise-Polar Characteristics - Type A.

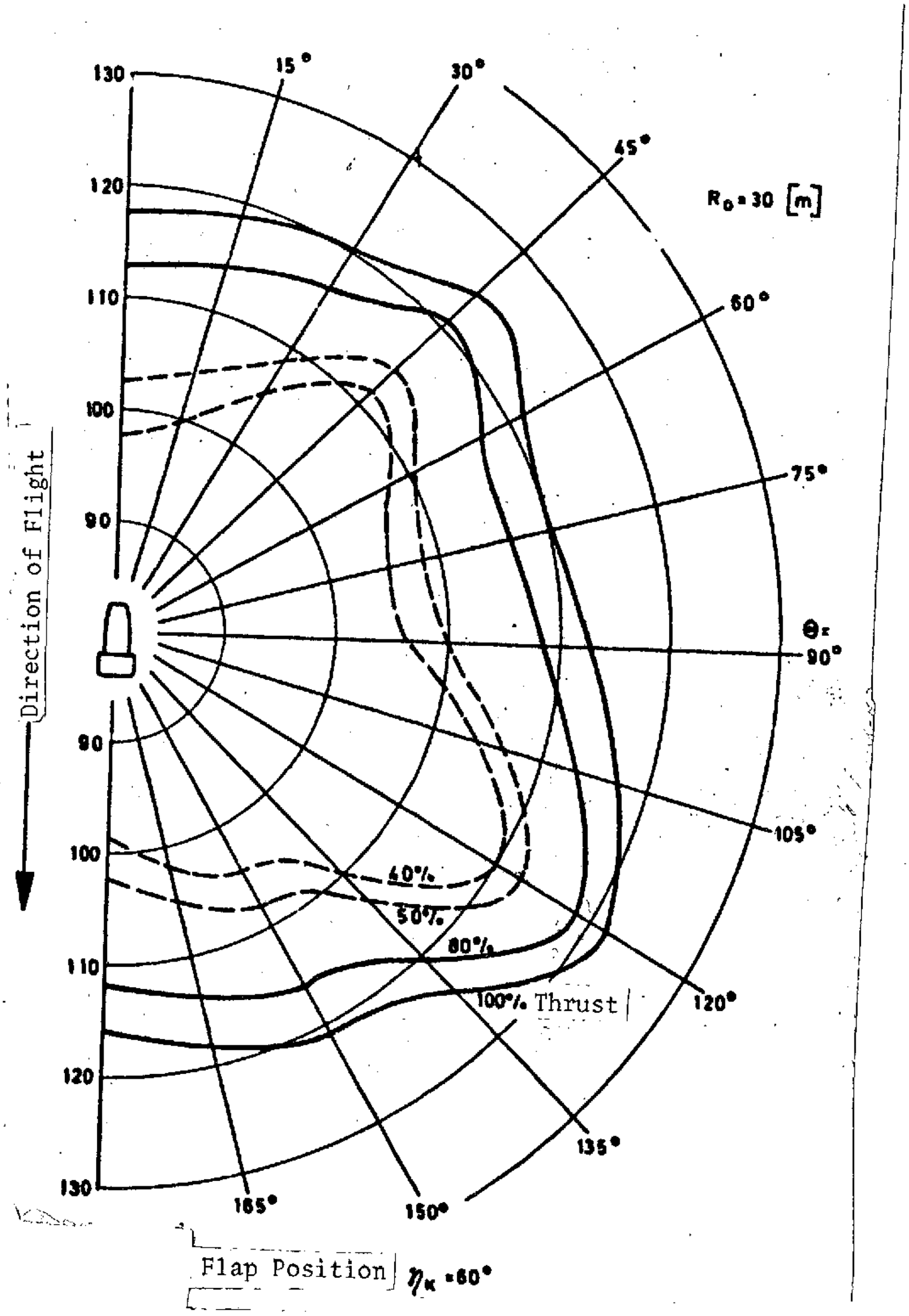


Figure 8. Noise-Polar Characteristics - Type B.

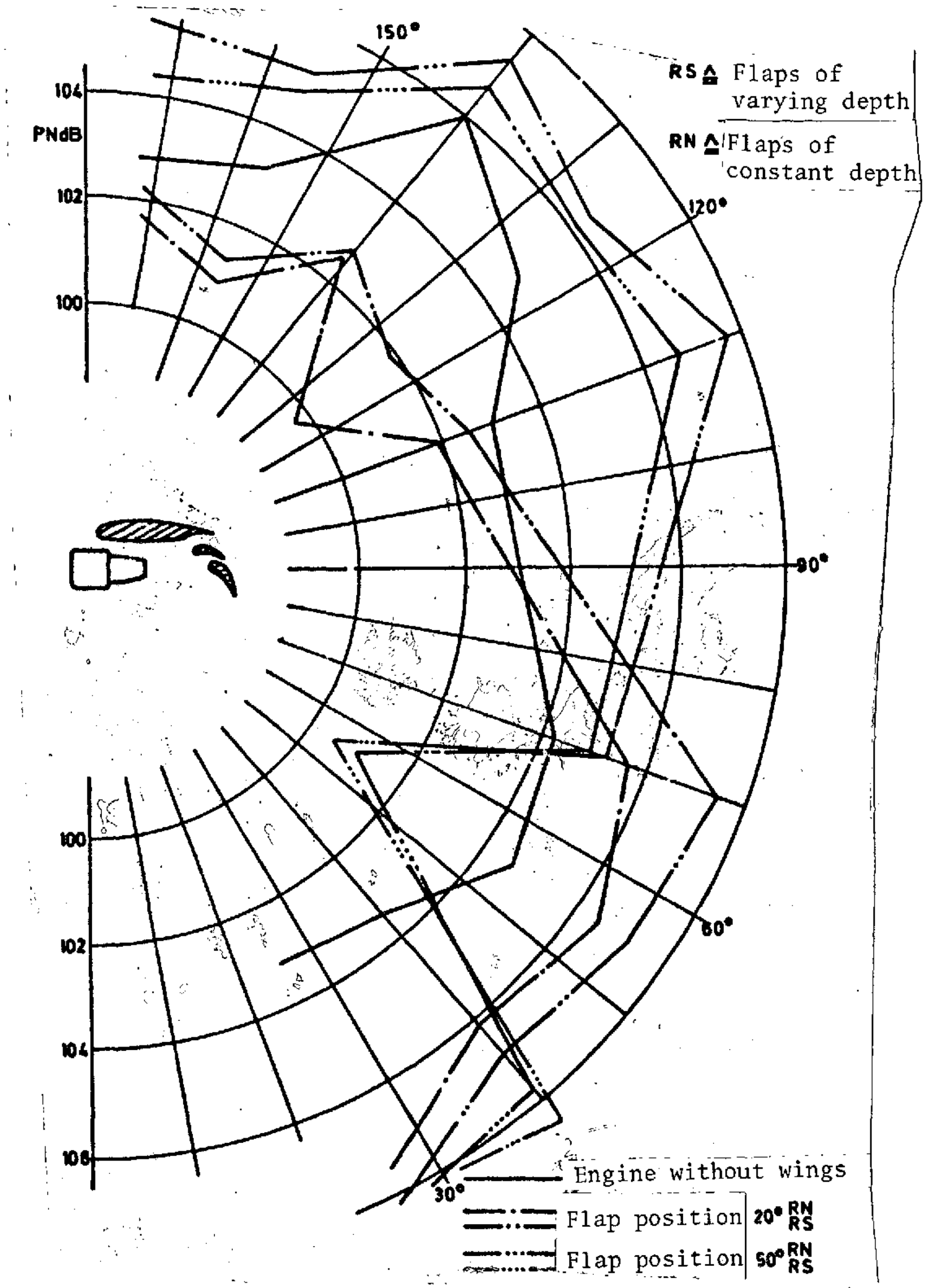


Figure 9. Noise Dispersion on "Externally Blown Flaps". Noise Dispersion in plane of symmetry.

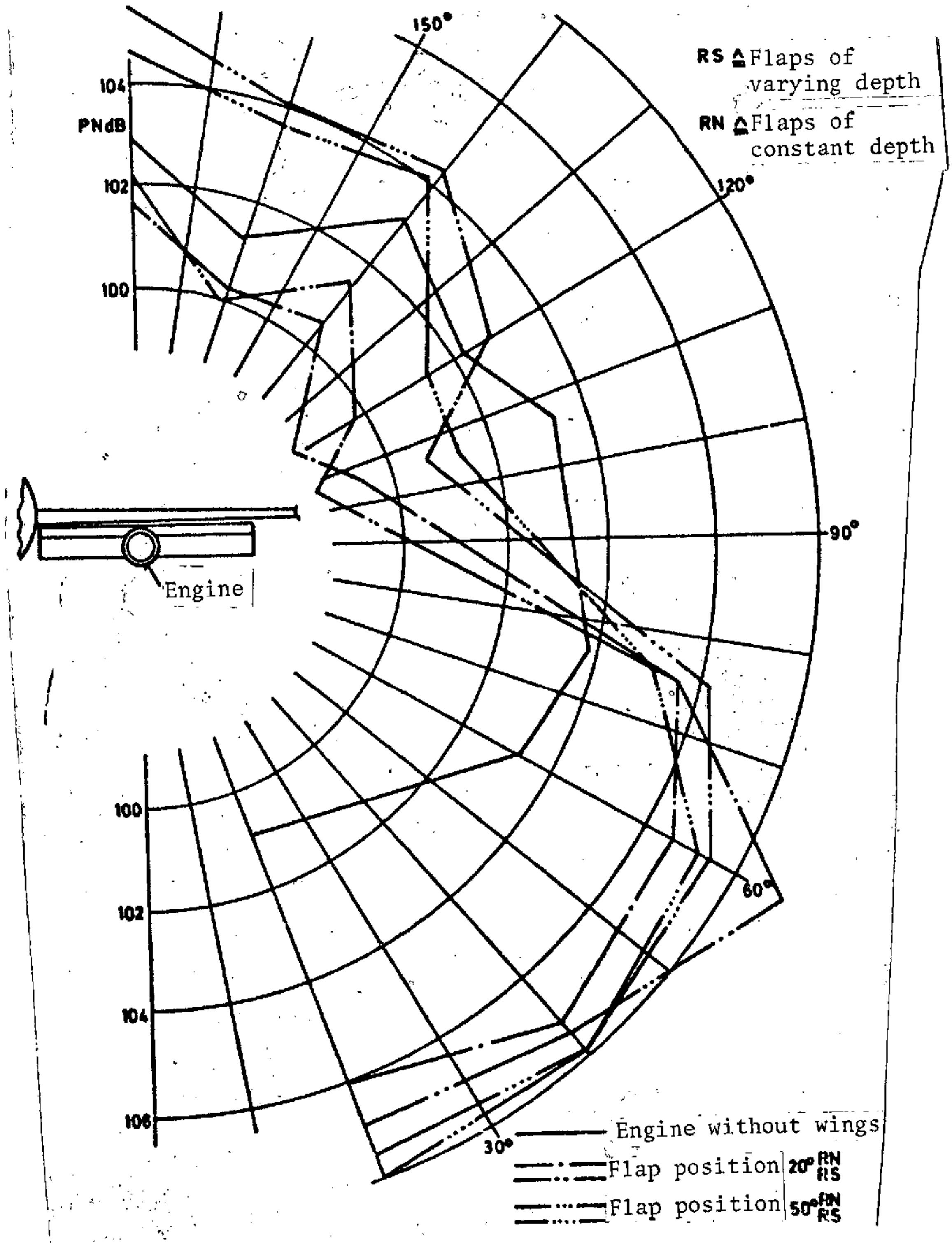


Figure 10. Noise Dispersion at "Externally Blown Flaps". Noise Dispersion to Side (Perpendicular to Plane of Symmetry of Aircraft).

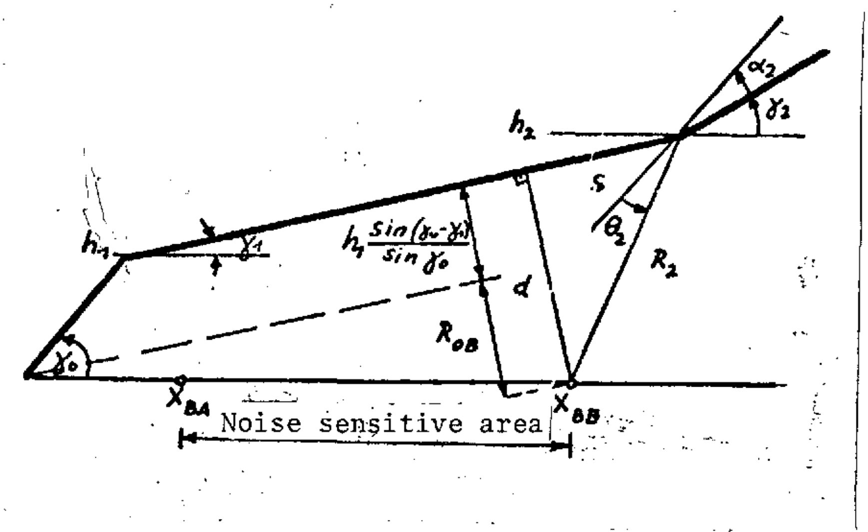


Figure 11a. Three Segment Takeoff Profile.

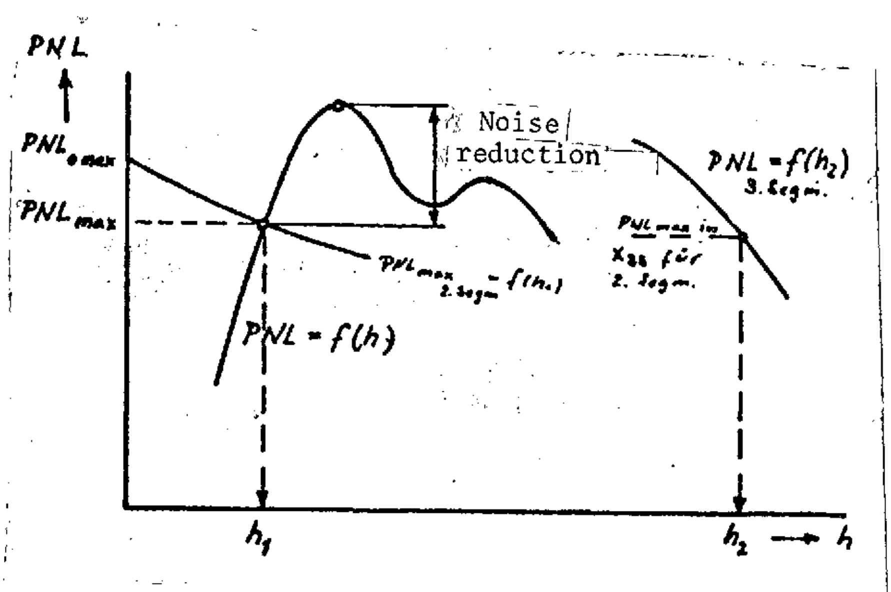


Figure 11b. Determination of Heights h_1 and h_2.

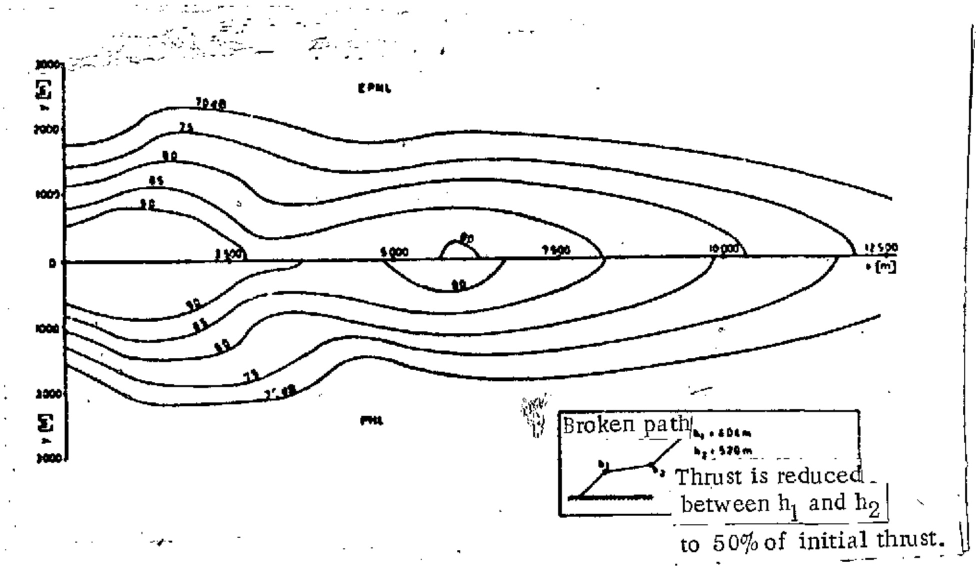


Figure 12a. Takeoff, Type A, Three Segment Starting Profile.

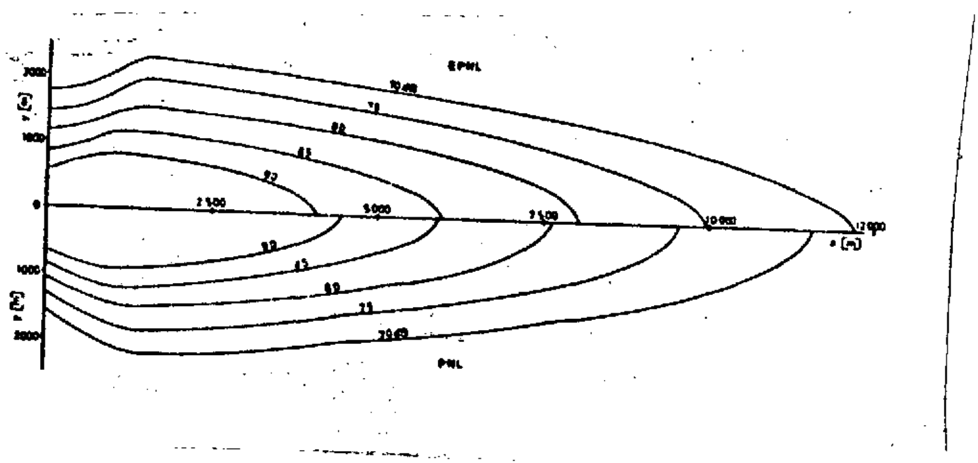


Figure 12b. Takeoff, Type A, EPNL and PNL Footprint for Straight Course.

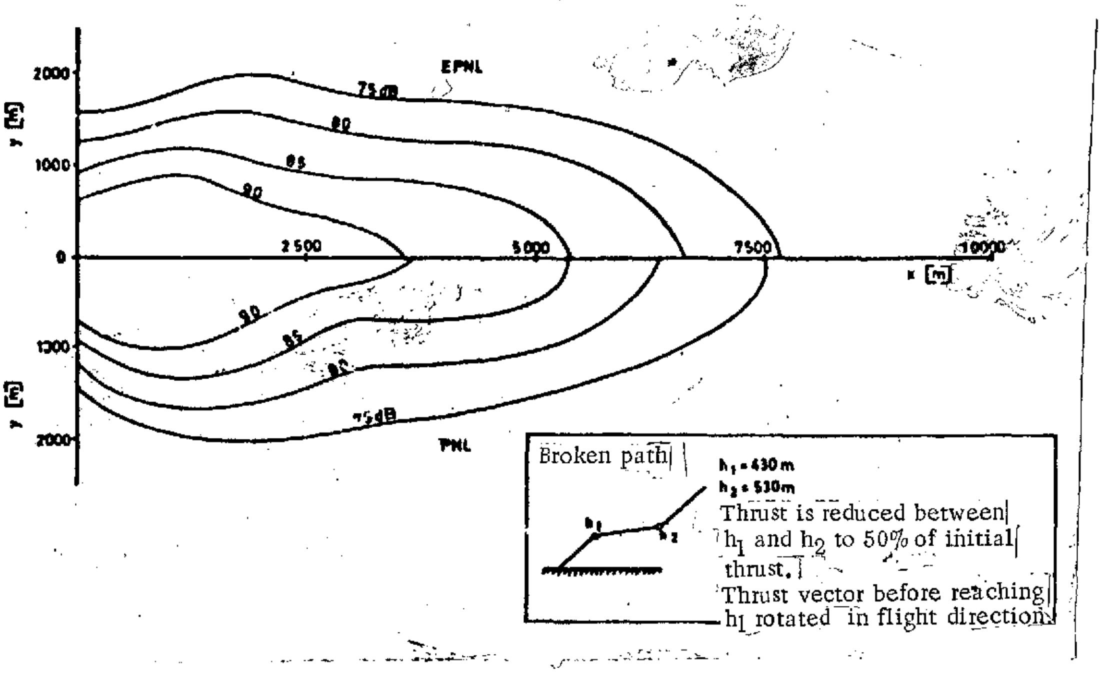


Figure 13a. Takeoff, Type C, Three Segment Takeoff Profile.

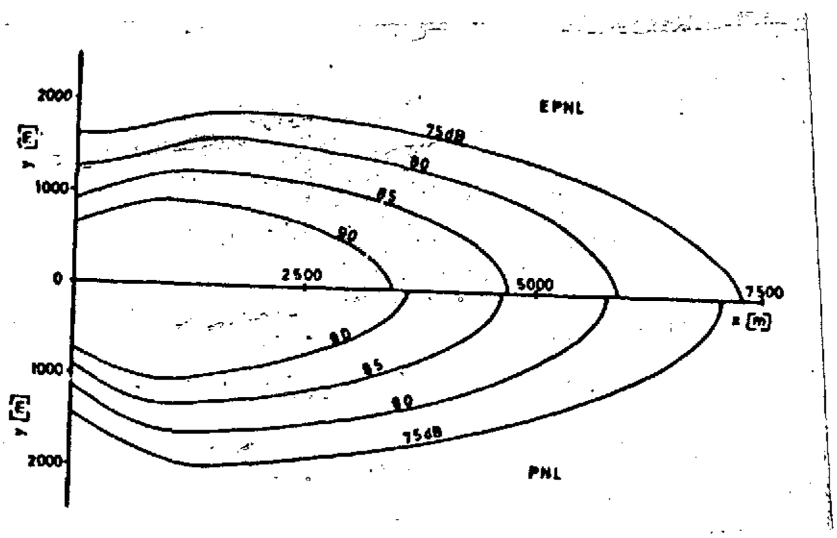


Figure 13b. Takeoff, Type C, EPNL and PNL Footprint for Straight Path.

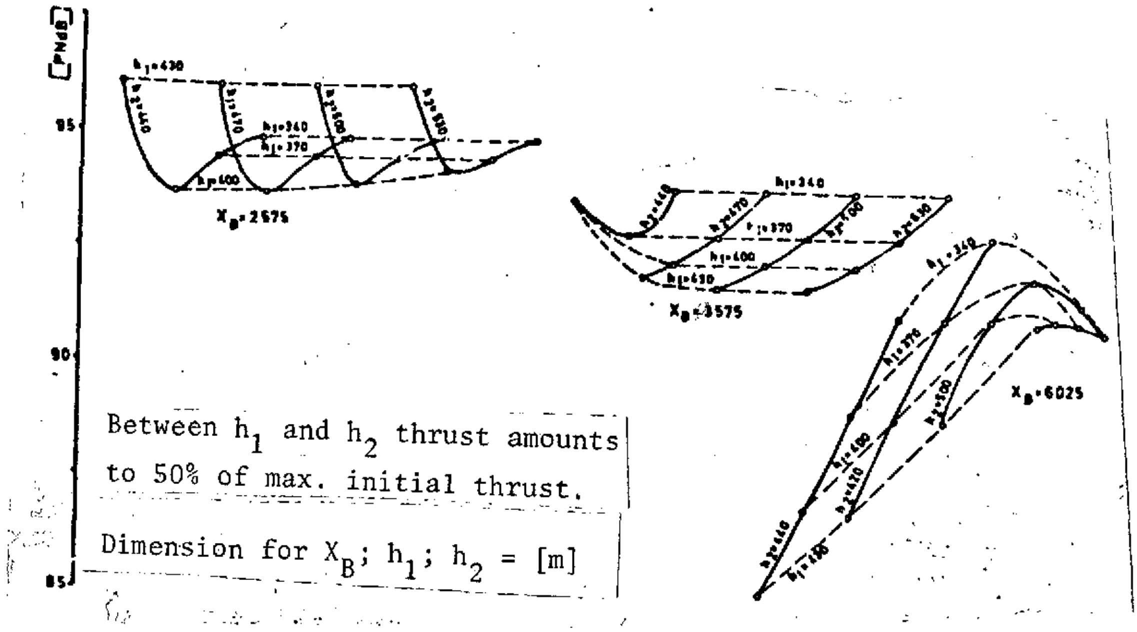


Figure 14a. Takeoff, Type A, Three Segment Starting Profile.

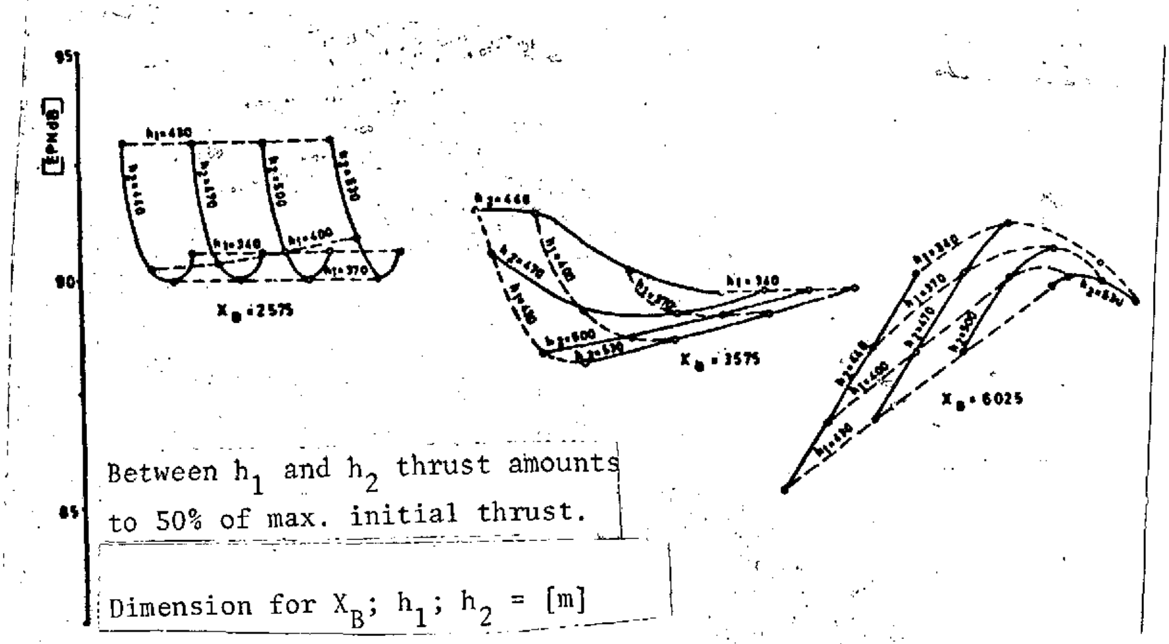


Figure 14b. Takeoff, Type A, Three Segment Takeoff Profile.

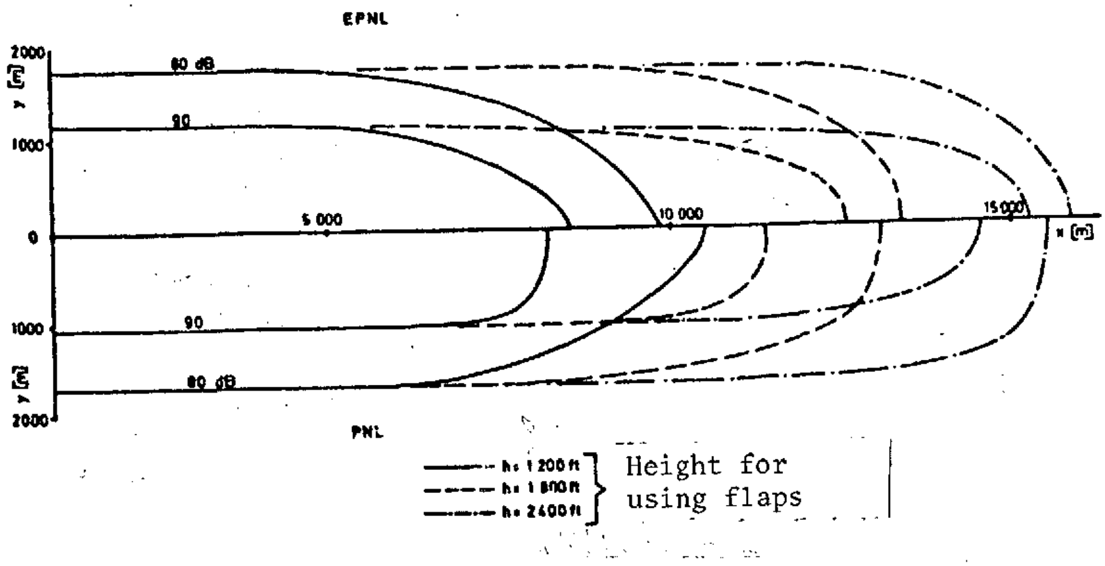


Figure 15a. Landing Approach, Type B.

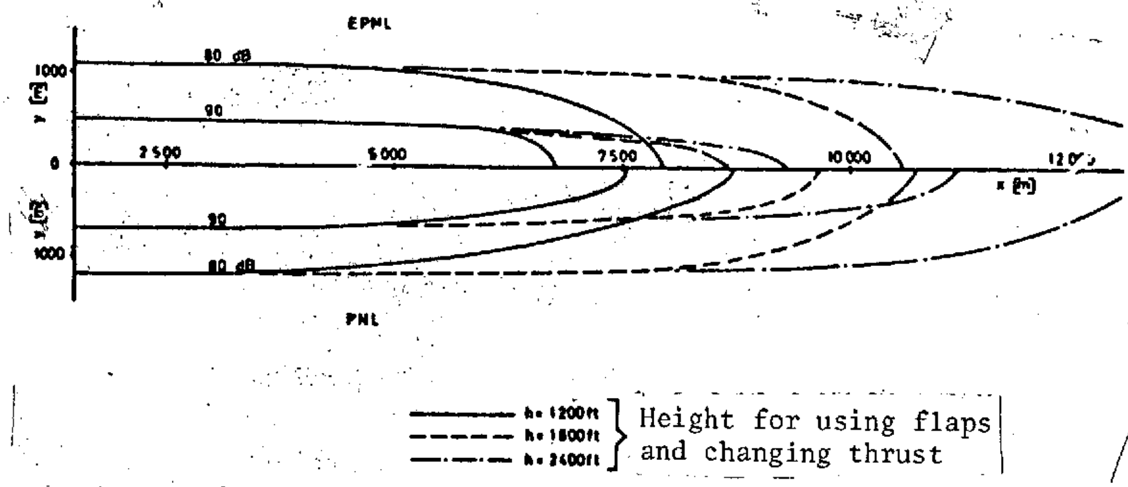


Figure 15b. Landing Approach, Type C.

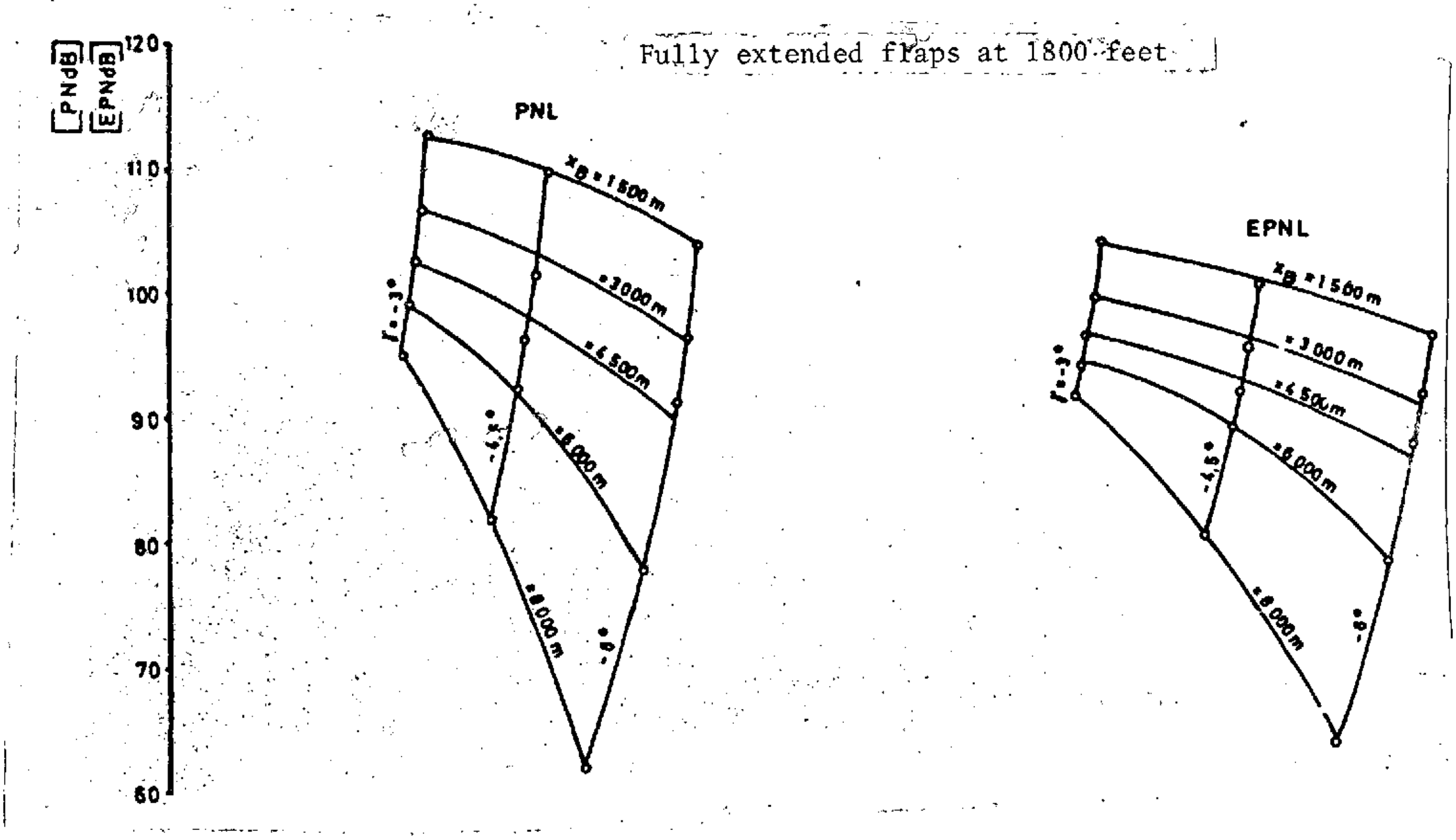


Figure 16. Landing, Type A, Approach on Straight Path with Varying Angles of Approach.

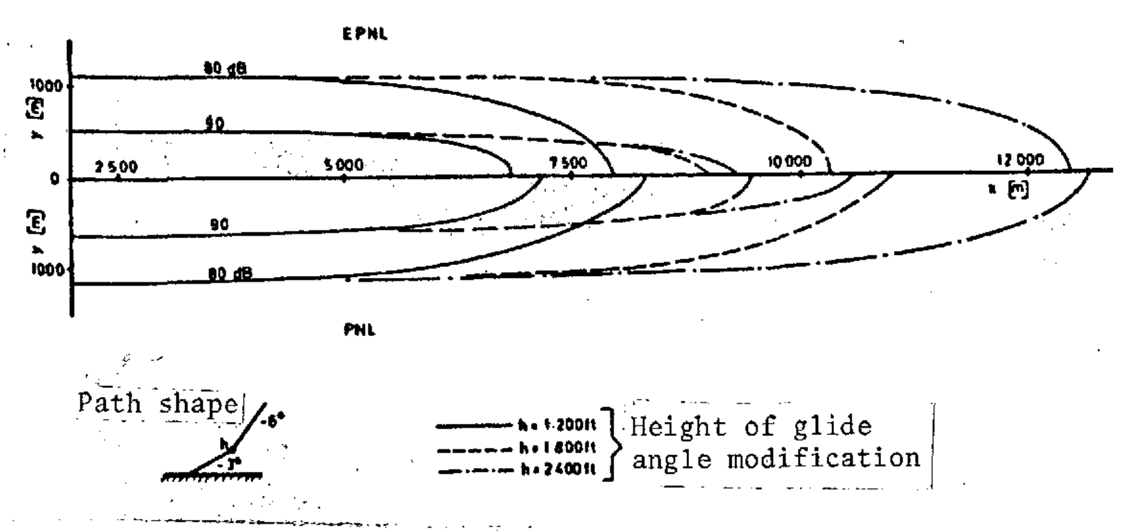
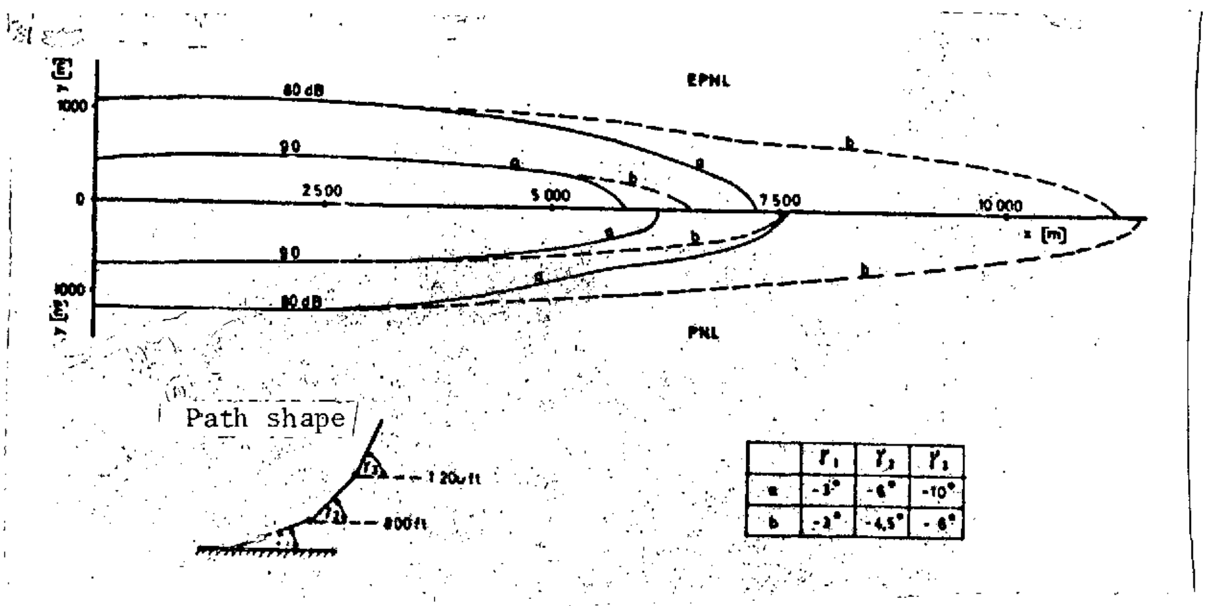


Figure 17. Landing, Type A, Approach on Simply Broken Path with Brake Point at Various Heights.



	γ_1	γ_2	γ_3
a	-3°	-6°	-10°
b	-2°	-4,5°	-6°

Figure 18. Landing, Type A, Doubly Broken Path, Landing Configuration for the Total Path Length.

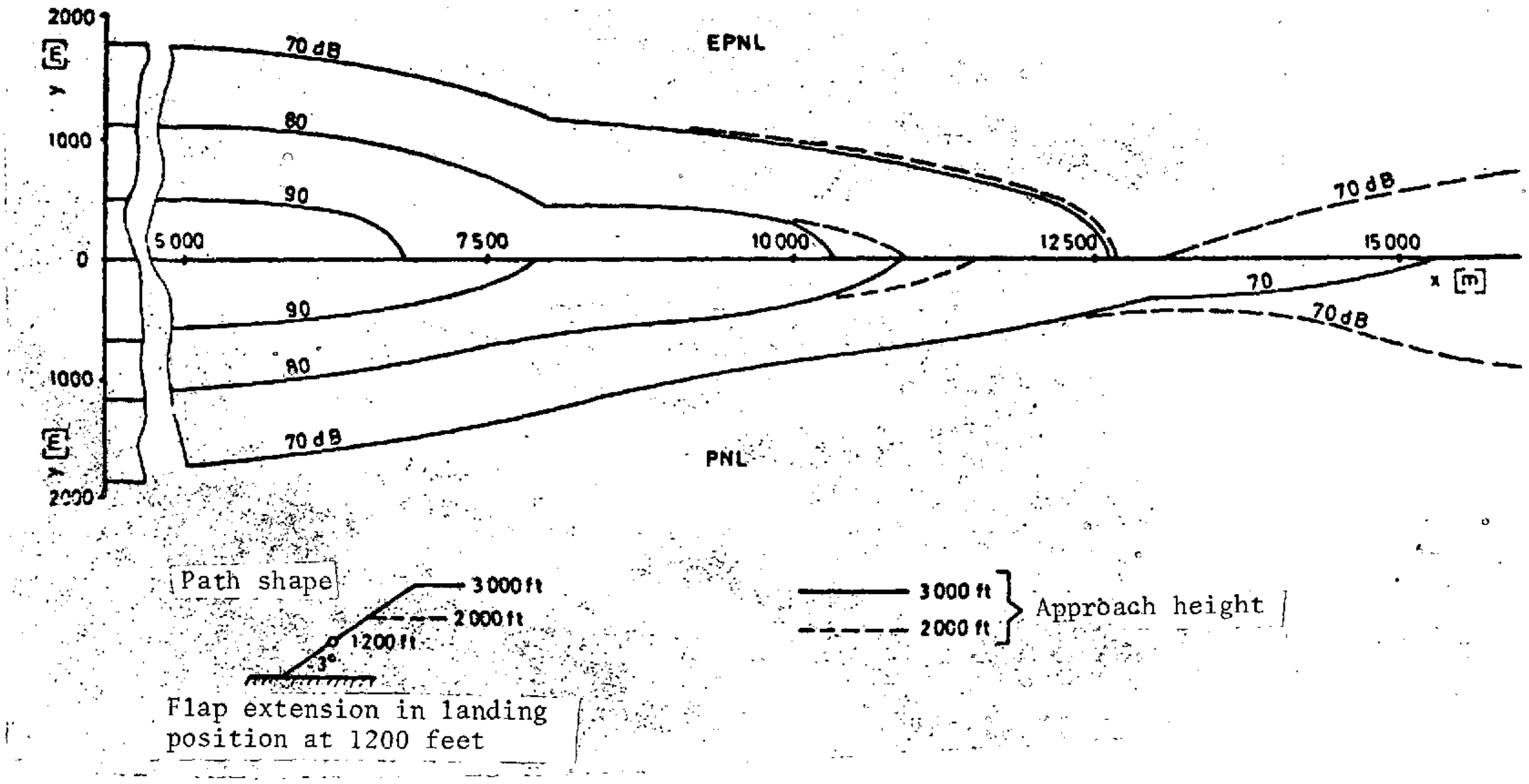


Figure 19. Landing, Type A, Horizontal Approach on -3° Glide Path at Various Heights.

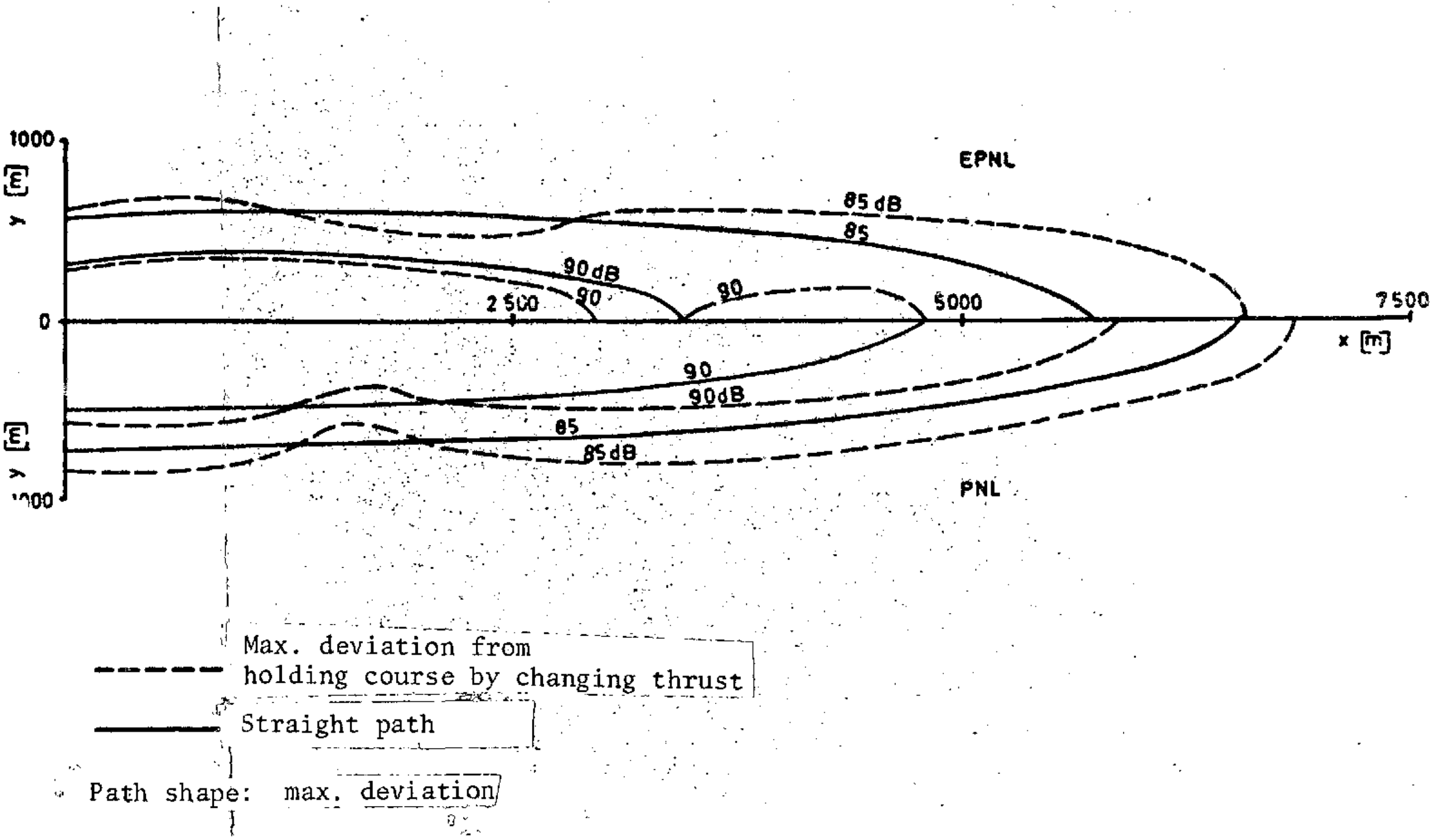


Figure 20. Comparison of Two Landings, Type A, = -6°.

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